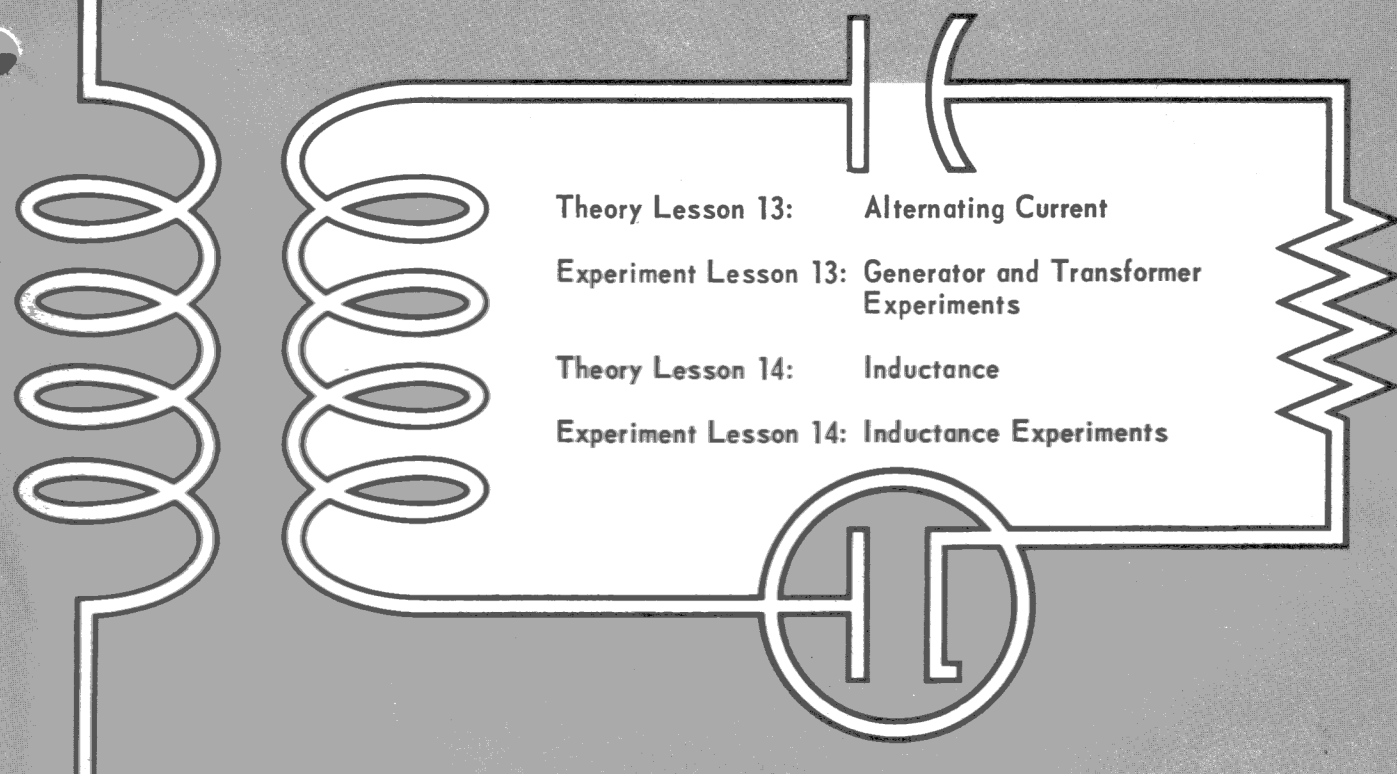


ELECTRONIC FUNDAMENTALS



Theory Lesson 13: Alternating Current

Experiment Lesson 13: Generator and Transformer Experiments

Theory Lesson 14: Inductance

Experiment Lesson 14: Inductance Experiments

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA
New York, N. Y.



ELECTRONIC FUNDAMENTALS

THEORY LESSON 13

ALTERNATING CURRENTS

13-1. A-C Values

13-2. Measuring A.C.

13-3. Rectifiers

13-4. Meter Loading



RCA INSTITUTES, INC.
A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL
350 West 4th Street, New York 14, N. Y.

Theory Lesson 13

INTRODUCTION

In your study of a-c generators, you found that alternating current constantly changes in *magnitude* (amount) and direction. You found that alternating current flows first in one direction and then in the opposite direction. Each change in direction, you remember, is called an alternation. These changes in current may be shown on a graph by using a sine wave. In addition, you found that a current is not induced. Instead, an emf is induced, and, as a result of the electrical pressure produced, current flows. From your knowledge of Ohm's Law, you know that *voltage* is equal to *current* times *resistance*. This means that the greater the current, the greater is the voltage. As the magnitude of current rises or falls in value, so does the magnitude of voltage rise or fall. Therefore, the magnitude of induced emf may also be shown by using a sine wave.

A sine wave can be drawn easily in the way that is shown in Fig. 13-1. First a horizontal line, *A-B*, is drawn. Next a point on

line *A-B* is selected. Using this point as the center, a circle starting at point *C* is drawn in a counterclockwise direction. This circle represents a rotation of a single conductor in an electromagnetic field. Point *C* represents the position of the conductor when its motion is parallel to the direction of the flux, where no voltage is induced, and no current is flowing. Let us call this position zero degrees. The next step is to lay off radii like spokes in a wheel. The more radii that are drawn, the easier it is to draw a perfect sine wave. In Fig. 13-1, radii are drawn for every 30 degrees of rotation. This produces twelve spokes. From point *D* on line *A-B*, twelve equally placed points are marked off to represent each 30 degrees of rotation. From these points, lines are drawn perpendicular to line *A-B*. Starting at the 30-degree point of the circle, a horizontal line is drawn to a point where it meets the 30-degree perpendicular. Next, from the 60-degree point of rotation, a line is drawn to the 60-degree perpendicular. Lines are drawn from each of the remaining 30-degree steps of rotation to the remaining vertical lines. As a result of

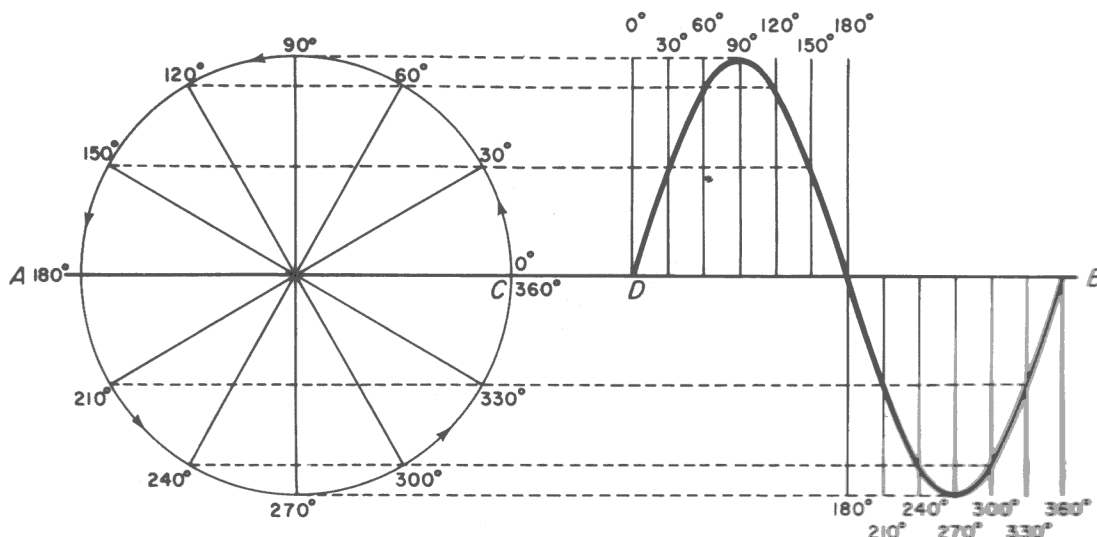


Fig. 13-1

connecting up the points where the horizontal lines meet the vertical lines, a sine wave is produced. This method of drawing a sine wave helps you to understand the wave shape of alternating current. Later on, similar drawings will help you to understand the production of wave forms you will see in oscilloscopes and TV receivers.

13-1. A-C VALUES

As you know, a-c voltage and current constantly change value. So, the voltage (or current) produced at any point in an a-c cycle is called the *instantaneous* voltage (or current). The sine wave represents all the instantaneous values of a.c. When we measure d.c., such as that delivered by a battery, it is easy to measure voltage or current accurately because the voltage and current are constant under a constant load. When we measure a.c., it is important to understand what we are measuring. Measuring the value at one instant does not give you the magnitude for the next instant. It doesn't do much good to take the peak or maximum value because this value is true only for two instants in every cycle. If we average all of the instantaneous values of the emf produced in one cycle of sine-wave a.c., we find that the sum of the values in the positive direction equals exactly the sum of the values in the negative direction. From this, we might assume that no emf is produced because the average value is zero. However, if you have ever touched or if you ever do touch alternating current supplied by the electric-power company, nobody has to tell you that electricity is actually flowing, even though it seems to add up to zero. For this reason, when we speak of average value of sine wave voltage or current, we average all of the instantaneous values *in one alternation* and realize that this average is true for the next alternation. Each alternation produces a change in polarity of voltage and direction of current.

In order to compare alternating current with direct current as to the amount of power consumed or work performed, we use the effective value, which, in some textbooks and articles on electronics, may be called the rms value. Rms means root-mean-square. We

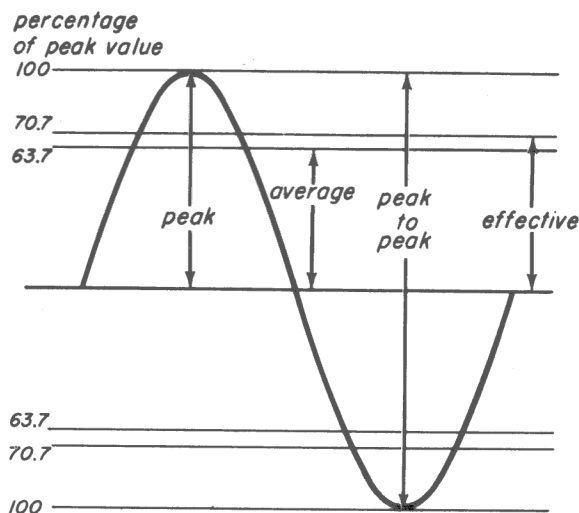


Fig. 13-2

call this the effective value because it is the value of a.c. that produces the same heating effect as the same value of d.c. For example, if 110 volts of d.c. produces so much heat, the value of a.c. that produces the same amount of heat is said to have an effective value of 110 volts. So, when we speak of an amount of alternating current or voltage, we always mean the effective value unless we say otherwise.

In talking about alternating current or voltage, we speak of the *average*, *effective*, *peak*, or *peak-to-peak* value. Figure 13-2 shows what we mean by these terms. For example, if the peak value is 100 volts, the average value is 63.7 volts, while the effective value is 70.7 volts. The swing from peak (maximum) in one direction to peak in the other direction is called the *peak-to-peak* value and is equal to twice the peak value.

The relationship between these a-c values is shown in Table A, which you will find very handy in converting from one a-c value to another. For example, to convert peak voltage to effective (rms) voltage, we multiply the peak value by 0.707. If the peak value is 150 volts, then:

$$E_{\text{eff}} = 150 \times 0.707 = 106 \text{ volts}$$

The table shows that the average value of a.c. is equal to 0.637 (63.7 percent) of the peak value. So, if the peak value is the same as before (150 volts), the average value is:

$$E_{\text{av}} = 150 \times 0.637 = 95.6 \text{ volts}$$

TABLE A - CONVERSION OF SINE WAVE A-C VALUES

Change To	peak	peak-peak	effective (rms)	average
peak		multiply peak by 2	multiply peak by 0.707	multiply peak by 0.637
peak-peak	multiply peak-peak by 0.5		multiply peak-peak by 0.353	multiply peak-peak by 0.318
effective (rms)	multiply effective by 1.41	multiply effective by 2.82		multiply effective by 0.901
average	multiply average by 1.57	multiply average by 3.14	multiply average by 1.11	

Using the same table, we can find the peak value of an a-c voltage or current with an effective value of 120 (volts or amperes). We just multiply the effective value by 1.41:

$$E_p = E_{eff} \times 1.41 = 120 \times 1.41$$

$$= 169 \text{ peak volts}$$

It is always necessary to say *peak volts* when we mean peak volts. If the word *peak* is left out, the value given is understood to mean the effective value. This is true also when we speak of average or peak-to-peak values.

When we use the oscilloscope to measure a.c., we sometimes speak of the peak-to-peak voltage. This is equal to the peak value in one alternation added to the peak value in the next alternation, or twice the peak value in one alternation. So, to find the peak-to-peak value, we multiply the peak value by two. If the peak value is 150, the peak-to-peak value is 300 volts.

13-2. MEASURING A.C.

To measure a.c., we cannot use the same meter that we use to measure d.c. If you try to measure a-c voltage with a d-c voltmeter, you will find that the meter either makes no

movement or flickers near the zero position. If we measure 60-cycle a.c., the movement cannot react rapidly enough to these changes in voltage, so the needle tends to remain in the zero position. However, as you will see shortly, it is possible to measure a.c. with the same D'Arsonval meter movement that measures d.c. Later in this lesson, you will see how this is done.

Hot-Wire Ammeter. In the early days of radio, a.c. was often measured by thermal meters — meters that use the heating effect in measuring electricity. They were popularly known as *hot-wire* ammeters. Because such meters depend on the heating effect of electricity, they may be used to measure both direct current and alternating current.

The theory of hot wire ammeters is not difficult to understand. You probably know that metals tend to expand (grow larger or longer) when heated. You may have noticed that railroad and trolley tracks are made up of lengths of metal rail, laid end to end. A little space is left between each length of rail so that, in the summertime, when the rails become heated, they may expand without buckling (bending or warping). Or you may have seen a drawbridge in the middle of summer that couldn't close properly be-

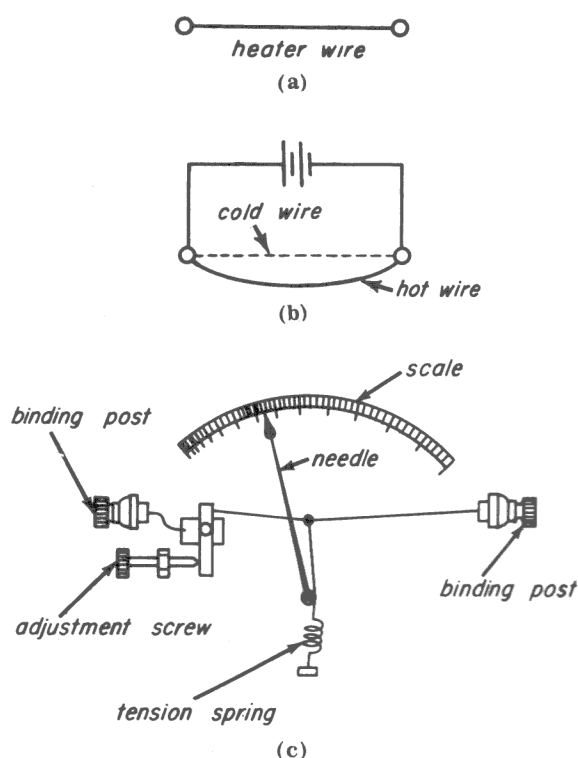


Fig. 13-3

cause the metal girders had expanded so much that the bridge could not go together until it cooled off a little. The principle of the expansion of metals when heated is used in the hot wire ammeter.

Figure 13-3a shows a length of wire stretched between two binding posts. The wire usually is made of either platinum or an alloy of silver and platinum. When current flows through this heater wire, as shown in Fig. 13-3b, it expands. If the center of the heater wire is connected to a pointer and spiral spring, as in Fig. 13-3c, the basic parts of a hot-wire ammeter are present. When current flows through the heater wire, it expands. This expansion produces a certain amount of slack in the heater wire, which is taken up by the spiral spring. Because the meter needle is tied to the wire between the heater and spring, it is caused to move as the spring takes up the slack in the expanded heater wire. The greater the current flowing through the heater wire, the greater is its expansion, and the greater is the movement of the meter needle.

While a hot-wire ammeter may be used for d-c or a-c current, it has several disadvantages:

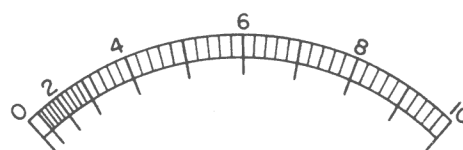


Fig. 13-4

1. It is slow in operation because of the time taken for the heater wire to rise to the temperature caused by the amount of current flowing through it.

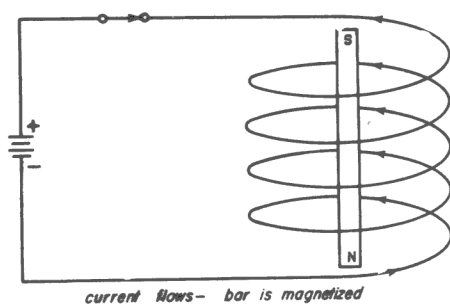
2. The heater wire reacts to changes in room temperatures. In a warm room, it expands, and the meter registers without any current flowing through it. This makes it necessary to adjust the pointer to zero each time it is used before taking any measurements.

3. The heating and expansion of the heater wire are in direct proportion to the power consumed by the heater wire. Power may be expressed as I^2R . For all practical purposes, the resistance of the wire remains the same; the increase in expansion of the heater wire is in proportion to the square of the current. As Fig. 13-4 shows, the scale of a hot wire ammeter is not linear; the calibrations at the low end of the scale are crowded together.

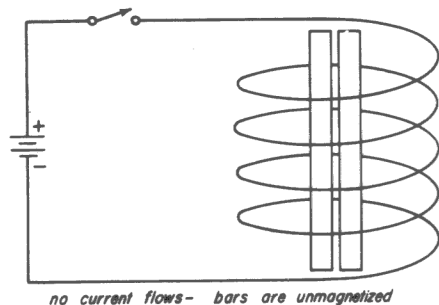
4. This type of meter is not sensitive. Large amounts of power are required to produce sufficient heat for the heater wire to expand enough to cause the needle to move.

Moving-Vane Meter. Another type of meter that has been, and still is, widely used in measuring a.c. is the *moving-vane*, or *moving-iron*, meter. The principle of the moving-vane meter is one that you already know something about. In your study of electromagnetism in Theory Lesson 10, you learned that when a piece of iron is inserted in a coil carrying current, the field caused by the current magnetizes the iron. You learned too, that the amount of magnetization depends on the strength of the magnetic field, which, in turn, depends on the amount of current flowing in the coil. Now let's see how this knowledge helps you understand the operation of a moving-vane meter.

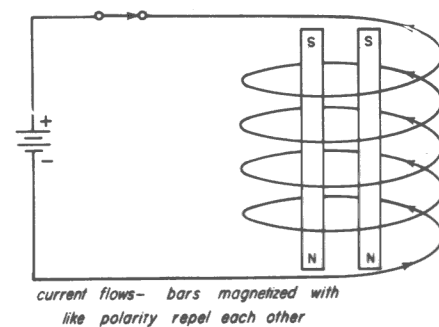
Figure 13-5a shows a piece of iron inserted in the coil that is carrying current. As



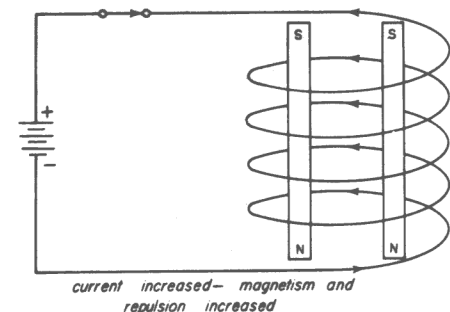
(a)



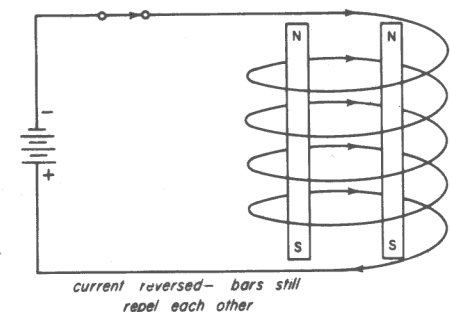
(b)



(c)



(d)



(e)

Fig. 13-5

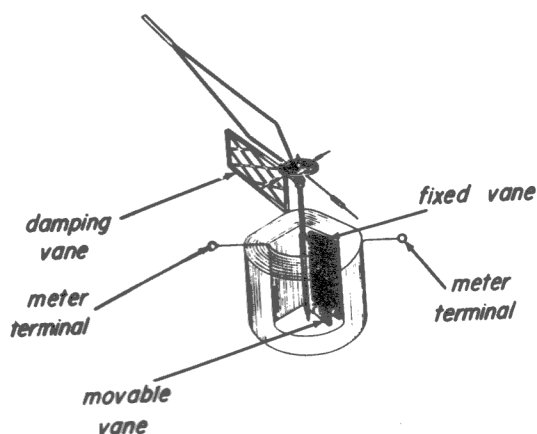


Fig. 13-6

the illustration shows, the iron becomes magnetized. Now suppose that two bars of iron are inserted in the coil, with no current flowing as in Fig. 13-5b. They remain side by side. However, as shown in Fig. 13-5c, when the current flows, a magnetic field is formed and the bars become magnetized, each with the same polarity as the other. Because they have the same polarity, they repel each other. If the current is increased, as it is in Fig. 13-5d, the magnetic field of the coil increases and the magnetism of the bars is increased, causing them to repel each other further. If the current is reversed, as in Fig. 13-5e, the polarity of the bars' magnetism is reversed, but they still repel each other.

When this principle is applied to a meter, as it is in Fig. 13-6, one bar (now called a vane) is fixed so that it cannot move. The other vane is pivoted so that it can move. This is called the moving vane, and the needle is attached to it. When current flows through the coil, the vanes become magnetized, and the movable vane is repelled by the fixed vane. As the movable vane pivots around to get away from the fixed vane, it causes the needle to move to a position on the meter scale that indicates the amount of current flowing in the coil. The aluminum vane mounted just below the needle is used to dampen the movement of the needle so that it comes to rest more quickly than it would without the vane. The damping vane, shown in Fig. 13-7, moves in a close-fitting compartment that causes the vane to be acted upon by air pressure to produce this effect.

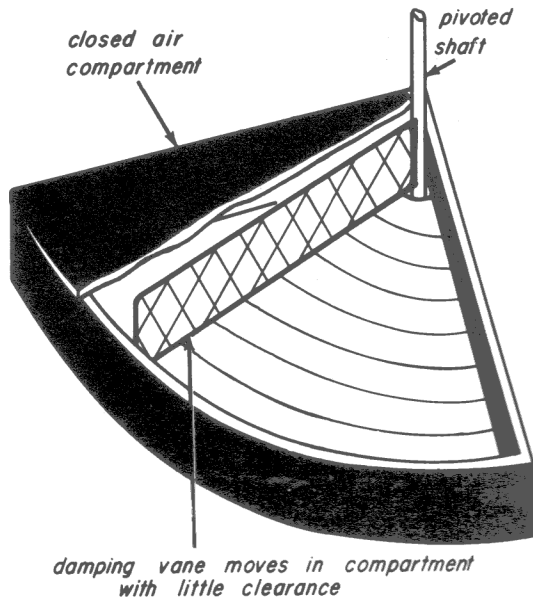


Fig. 13-7

While the moving-vane meter is more sensitive than the hot-wire meter, it requires considerably more current on which to operate than does a D'Arsonval movement in measuring d.c. Like the hot-wire ammeter, it has a square-law meter scale that is crowded at the low end of the scale.

Electrodynamometer. We studied in an earlier lesson a meter that may be used to measure a.c. It is the electrodynamometer. This meter uses a moving coil and fixed coil. When used to measure a.c., the magnetic polarity of both electrodynamometer coils is the same at any instant in the a-c cycle. This means that when current flows in these coils, the like polarities will cause the movable coil to be repelled by the fixed coil, and the needle attached to the movable coil will indicate the amount of current flowing through the meter.

Thermocouple. The D'Arsonval meter movement may be used to measure a.c. if the a.c. is first changed to d.c. This can be done in two ways. The first of these methods uses a thermocouple. A thermocouple is basically nothing more than two unlike metals, such as iron and an alloy of copper and nickel, joined together. Figure 13-8a shows such a thermocouple being heated at the point where the two metals join. This produces a voltage, called a *thermoelectric d-c voltage*, at the free ends

of the couple, *A* and *B*. The hotter the thermocouple becomes, the greater is the voltage produced. If a sensitive meter is connected to terminals *A* and *B*, it will measure the voltage produced. Because this voltage is always d.c., we may use a D'Arsonval meter movement for this purpose.

Instead of using a flame to heat the couple, we can substitute a heater (resistance) wire connected to the point where the couple is joined. Such a thermocouple is shown in Fig. 13-8b. Current flowing through the heater wire produces heat which heats the couple. It does not matter whether the current is d.c. or a.c.; the heating effect on the heater wire is the same for equal amounts of current. So, by using a thermocouple, we can measure a.c. with a d-c meter movement.

As you can see, thermocouple meters may be used to measure either a.c. or d.c. However, there is no particular advantage in using it to measure d.c. because a thermo-

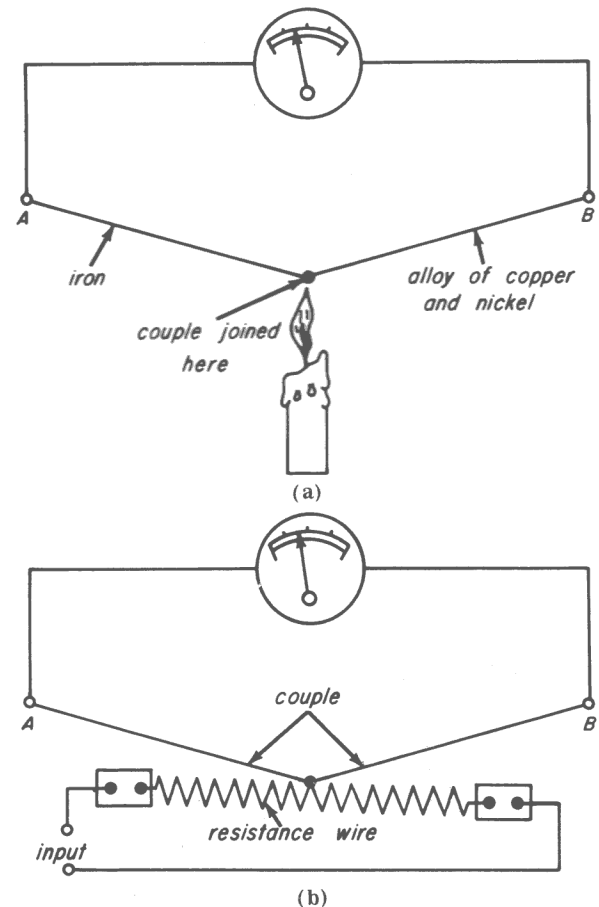


Fig. 13-8

couple meter has a square-law scale, with calibrations crowded together at the low end. Thermocouple meters are widely used to measure current at radio frequencies, but there are some disadvantages to their use. These are:

1. Since the voltage of the thermocouple depends upon the amount of heat received by the couple from the heater wire, any heat from the heater wire that is lost to the surrounding air will cause an error in the meter reading. To reduce such heat loss and to increase the accuracy of the meter readings, thermocouples are sometimes placed in glass envelopes from which the air has been removed.

2. If a thermocouple is overloaded, the heater wire is liable to burn out. When this happens, it is necessary to get a replacement thermocouple, connect it to the meter in place of the thermocouple that is burnt out, and then recalibrate the meter (usually by adjusting the values of the multiplier resistors).

3. Thermocouples, because they are very delicate, need very careful handling — more so than most meters used by radio and TV servicemen.

4. Unless the meter movement is specially designed to be used with a thermocouple, the low readings are all crowded together. Specially designed meters are more expensive than standard D'Arsonval movements.

13-3. RECTIFIERS

The method most often used in radio and TV test equipment to change a.c. to d.c. is called *rectification*. Rectification is performed by a device that permits current to flow in one direction only. A *rectifier*, a device that permits the free flow of current in one direction and which offers high resistance to the flow in the opposite direction, is used to change a.c. to *pulsating* d.c. You remember, from your study of generators, that the induced a.c. is converted to pulsating d.c. by means of a commutator, which actually is a switching device. It is possible to use a mechanical switching action for rectifying a.c. Some vibrators used in auto radios provide such action, as you will find when you

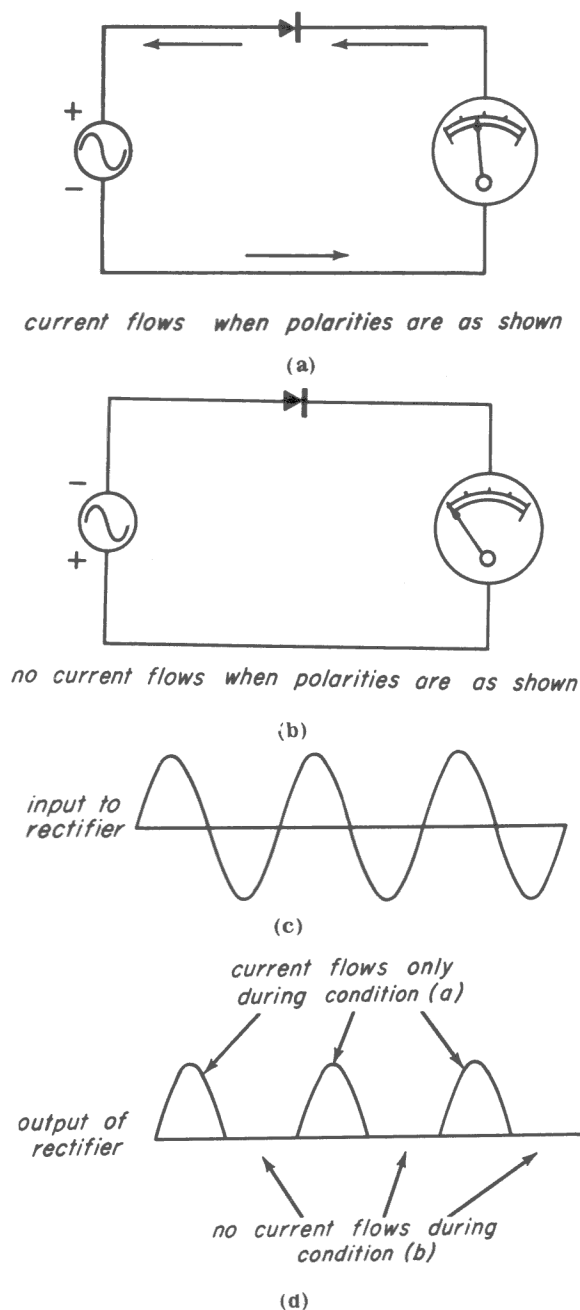


Fig. 13-9

study the Service Practices booklet that deals with servicing auto radios. However, this method is not practical for use in meter rectification. Most of the meters used by radio and TV servicemen for measuring a.c. use a dry-disk, a crystal-diode, or an electron-tube diode rectifier. Theory Lesson 17 discusses the action of diodes and other rectifiers completely. At this time, it is necessary only that you understand the *effect* that a rectifier has upon a.c.

Figure 13-9 shows a simple rectifier cir-

(the current flowing through the meter) is pulsating d.c. Because current flows only during one alternation of each cycle, the d-c pulses are separated by the time of one alternation. We call this *half-wave* rectification because only one-half of the sine wave is rectified. The meter needle deflects up-



scale because the pulses are all in the same direction. It does not register the peak value nor does it drop to zero between pulses. Instead, it moves to a position part way between these two points. The needle moves to a point equal to all of the instantaneous values of one alternation (pulse) averaged over a period of one cycle.

When we discussed the average value of sine-wave a.c. in the beginning of this lesson, we said that this value of a.c. was found by averaging all of the instantaneous values of one alternation. We said, too, that the average value for one alternation equals the average for the next alternation. However, in half-wave rectified a.c., this average value is spread over two alternations — one when current flows and one when there is no current. It is just half the amount that there would be if current flowed during both alternations of each cycle. If the average value of sine-wave a.c. equals 0.637 times the peak value, the same amount averaged for one cycle (two alternations) must equal $0.637 \div 2$ times the peak value, or 0.318 times the peak value of the a.c. delivered by the generator to the rectifier-meter circuit. If you look at Table A again, you'll find that the average value of a.c. is equal to about 90% of the effective value. Half of this value is 45%. Therefore, the meter needle will deflect to a point that represents 45% of the effective value of a.c. However, the meter scale may be marked with the effective value; if so, readings may be taken directly in effective values and there is no need to calculate them.

In practical meter circuits, multipliers are used to limit the current flowing through the meter when the voltage being measured exceeds the capacity of the meter movement. Such series resistors are used when a.c. is rectified and measured. For example, on the 15 VAC range, your multimeter has a total multiplier resistance of 98 k-ohms in series with the meter movement and the diode as shown in Fig. 13-10. The use of any multiplier in series with the rectifier-meter circuit affects the efficiency of the circuit. Let us consider why this is so.

The ideal rectifier would be one that of-

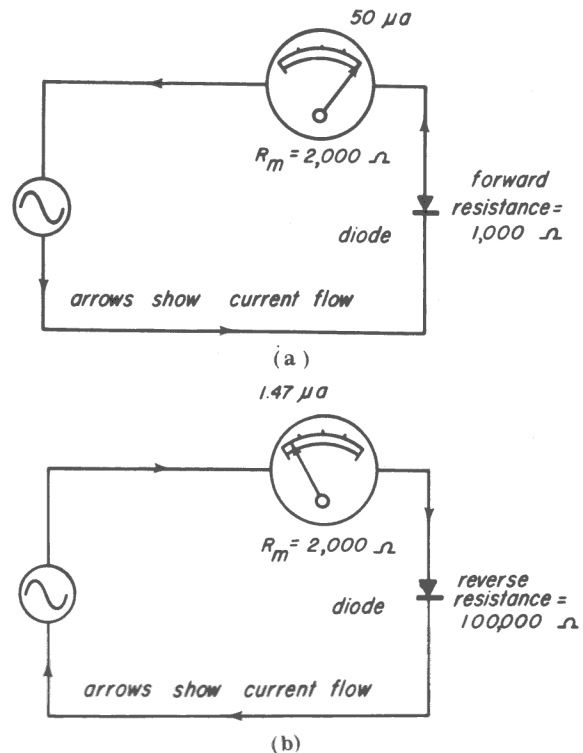


Fig. 13-11

fered no resistance to the current in one direction and infinite resistance to current in the opposite direction. Actually no such rectifier exists. The rectifier's forward resistance (the resistance offered by the rectifier when it is supposed to conduct) varies with the type used; but, in every rectifier, there is some forward resistance that varies with the current flowing through it. The reverse resistance (the resistance of the rectifier when it is not supposed to conduct) is not infinite but is a measurable amount. In efficient rectifiers, the reverse resistance is 50 or 100 or more times the forward resistance. This means that a very small amount of current flows through the rectifier circuit during the half cycle when the rectifier is not supposed to be conducting. Such current is called *reverse current* or *leakage current*. To learn how this affects the efficiency of the rectifier-meter circuit, we'll examine the rectifier section of your multimeter circuit.

Figure 13-11a shows the rectifier-meter circuit of your multimeter (without a multiplier resistor) during the forward-current period. Let us say that the forward resistance of the diode is 1,000 ohms. The equivalent circuit, shown in Fig. 13-11a, is equal to 1,000

RMS

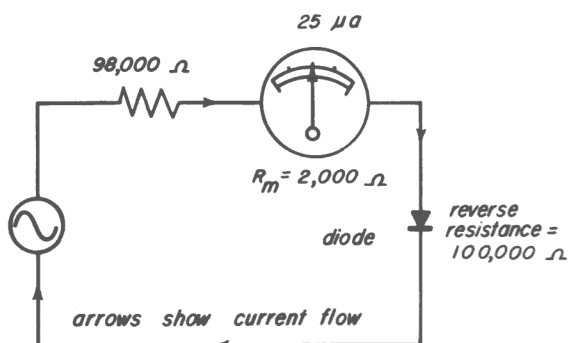


Fig. 13-12

ohms (the rectifier resistance) in series with 2,000 ohms (the meter resistance). Let us suppose that we apply sufficient voltage to produce a full-scale reading on the meter ($50 \mu\text{a}$). When the polarity of the voltage reverses, as shown in Fig. 13-11b, the reverse resistance of the rectifier adds to the resistance of the meter to offer opposition to current flow. The reverse resistance of the crystal diode is about 100 times the forward resistance. Therefore, the reverse resistance is about 100,000 ohms. This resistance, added to the 2,000 ohms of the meter makes a total of 102,000 ohms opposing the flow of current. The ratio of the total circuit resistance in the forward direction to the total resistance in the reverse direction is:

$$\frac{3000}{102,000} = \frac{1}{34}$$

The current flowing in the reverse direction is $1/34$ of $50 \mu\text{a}$, or $1.47 \mu\text{a}$. The efficiency of the rectifier-meter circuit is $33/34$ or 97 percent.

However, when a 98 k-ohm multiplier is placed in series with the circuit, as it is on the 15 VAC range on your multimeter, the circuit resistance becomes as is shown in Fig. 13-12. The total circuit resistance in the reverse direction is $98 \text{ k} + 2 \text{ k} + 100 \text{ k} = 200 \text{ k-ohms}$. The ratio of total forward to reverse resistance is:

$$\frac{101 \text{ k}}{200 \text{ k}} = \frac{1}{2} \text{ (approx)}$$

This means that about half the amount of current that flows in the forward direction flows in the reverse direction. The efficiency of the rectifier-meter circuit is only 50 per-

cent. On the higher ranges, the efficiency becomes worse.

However, high efficiency is obtained by adding another half-wave rectifier (diode 1) as shown in Fig. 13-14. With this second diode, the efficiency of the rectifier-meter circuit of your multimeter is high, even with multipliers added to the circuit. If anything, the efficiency goes up slightly as the value of the series multiplier increases. Let's see why this should be so.

Figure 13-14a shows the path of current when the circuit is operating in the forward direction. In this direction, current flows through the meter. Figure 13-14b shows the current path when the circuit is operating in the reverse direction. In this direction, practically no current flows through the meter. Instead, it returns through diode 1. The equivalent circuit with the meter in the 15 VAC position is shown in Fig. 13-15. As you can see, between points A and B, there are two parallel paths in which current may flow. One offers a resistance of 1,000 ohms to the flow of current; the other offers a resistance of 102,000 ohms to the flow of current. More than 99 percent of the current will flow through the low-resistance path of diode 1 and less than one percent will flow through the meter. In this way, efficient half-wave rectification is made possible.

Full-Wave Rectification. Another method of rectification, one that rectifies both alternations of each a-c cycle, is called full-wave rectification. As you can see in Fig. 13-16, four half-wave rectifiers are used. This type of circuit is called a bridge circuit, and it is important that the parts of a bridge circuit be evenly balanced. For this reason, the four half-wave rectifiers are carefully selected so that they match each other in forward and reverse resistance to provide proper balance in the rectifier bridge.

Let's see what happens when sine-wave alternating current is applied to the terminals

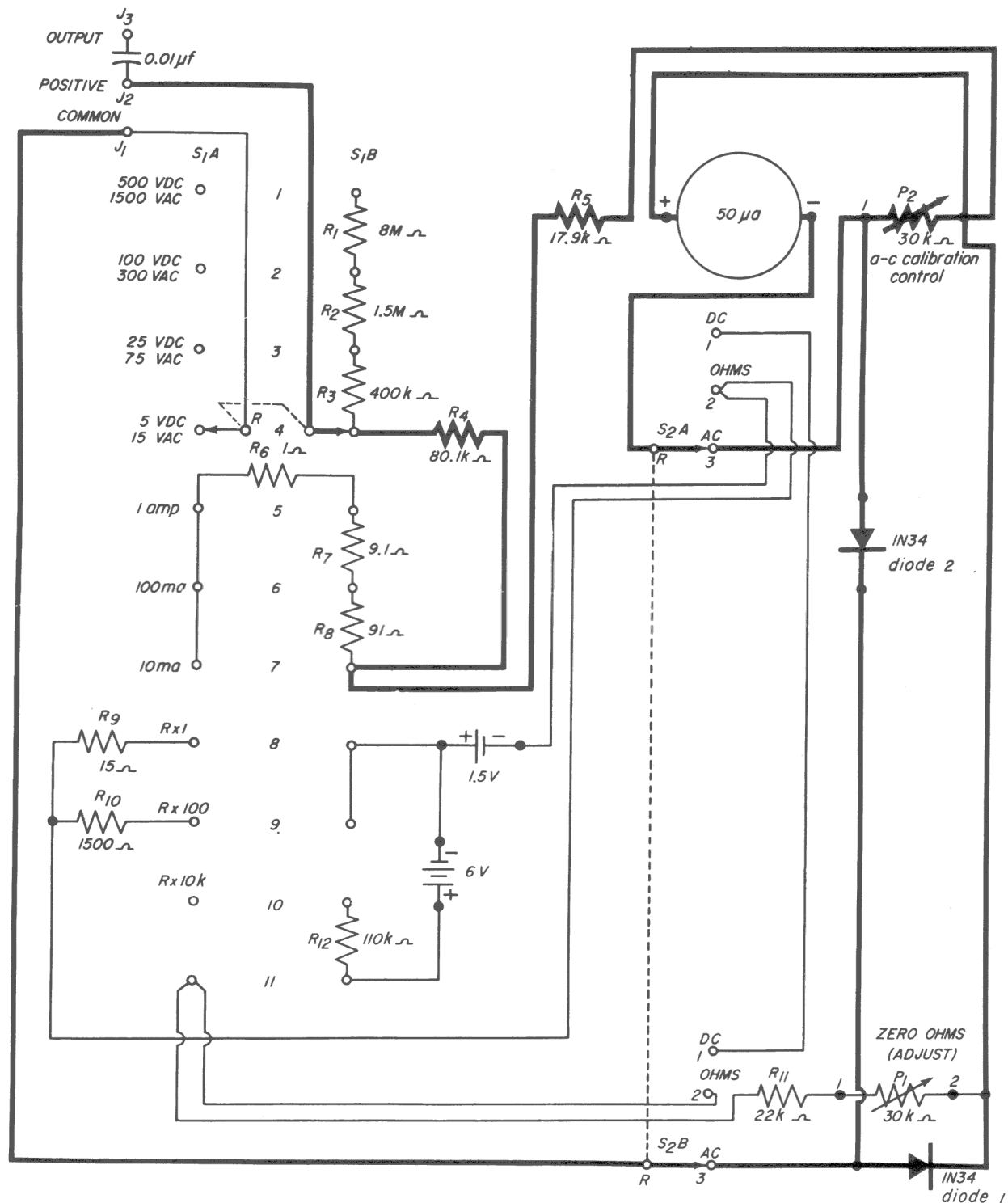


Fig. 13-13

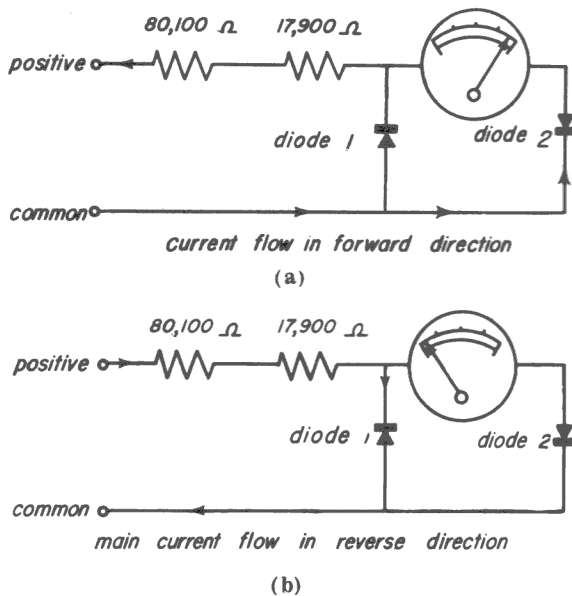


Fig. 13-14

of the circuit. Figure 13-17a shows the direction of current flow during one half-cycle. The current flows in the directions shown from terminal A to point B in the bridge. The high reverse resistance of rectifier 1 prevents current flow from B to D, so current flows through rectifier 2 to point C in the bridge circuit. Rectifier 3 stops current from flowing from C to E; therefore, current flows through the meter to D. As you know, current flows only when there is a difference in potential. For that reason, current does not flow back through rectifier 1 to B. Instead, it flows from D through rectifier 4 to E and then on to terminal F.

During the next half-cycle, current flow is in the opposite direction, as shown in Fig. 13-17b. Follow the current flow from terminal F to point E. Rectifier 4 prevents the flow of

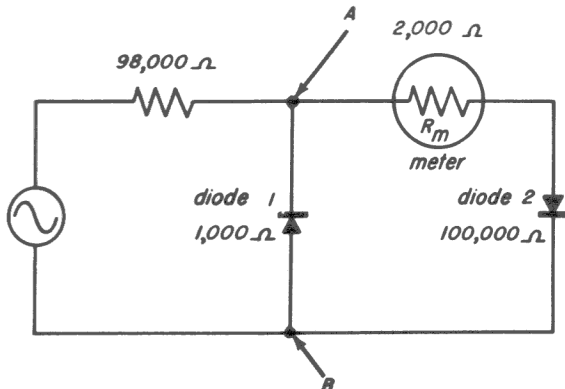


Fig. 13-15

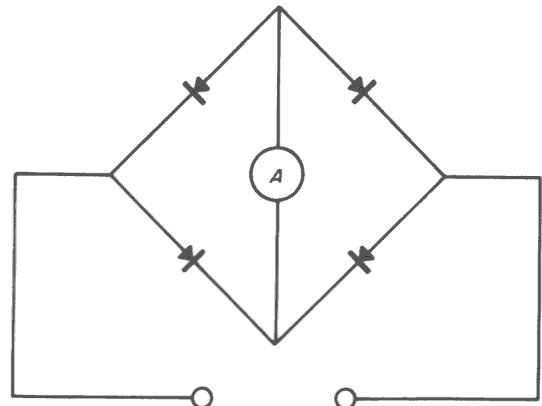


Fig. 13-16

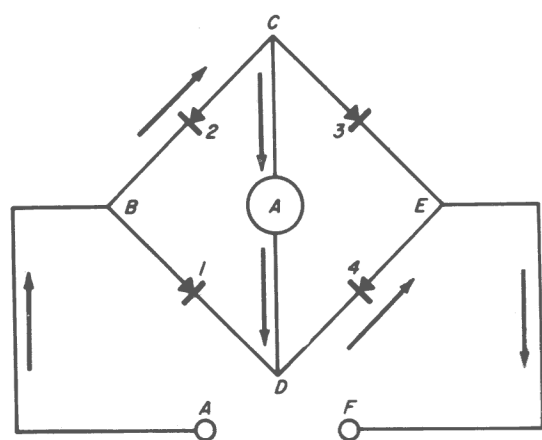
current from E to D. It flows from E, through rectifier 3, to C. From this point, current cannot flow to B because rectifier 2 does not conduct in this direction. So current flows from C, through the meter, to D. From D, it flows through rectifier 1 to B, and on to terminal A, thus completing the circuit.

Notice that in both half-cycles, the flow of current through the meter is in the same direction. As shown in Fig. 13-18, both alternations of the sine-wave input are rectified; the meter receives two pulses in the same direction for each cycle of current flow. As is the case with half-wave rectification, the meter movement shows the average value of the current pulses flowing through it. Because both alternations of each cycle are rectified, the meter needle deflects to a point that represents 0.637 times the peak value.

13-4. METER LOADING

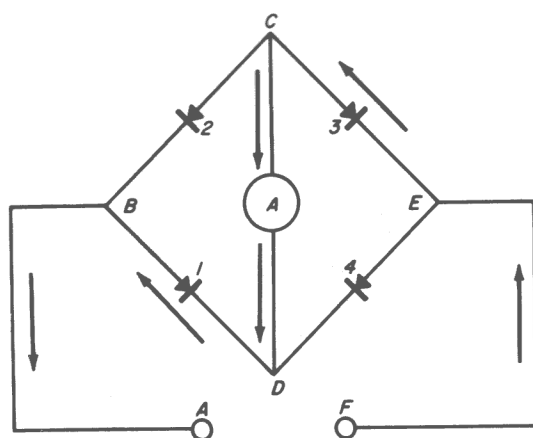
In your study of d-c meters, you learned that such meters tend to load the circuit under test and that the loading becomes less as the resistance of the meter circuits increases. For example, the resistance offered by the 5-volt range of a 20,000-ohms-per-volt meter is 100,000 ohms, while the resistance of the 5-volt range of a 1,000-ohms-per-volt meter is only 5,000 ohms. The first meter would tend to load a circuit much less than the second meter.

A-C meters load circuits under test in much the same way. A hot-wire ammeter, because it has a very low resistance, is used only to



current flow in first half cycle

(a)

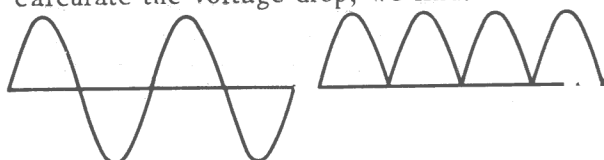


current flow in second half cycle

(b)

Fig. 13-17

measure current. Iron-vane meters are usually made with sensitivities no higher than 200 ohms per volt. On the 5-volt range, such a meter offers a load of 1,000 ohms on the circuit under test, which makes it a poor instrument for measuring audio or r-f voltages in high resistance circuits. For example, see what happens if we try to measure the signal voltage appearing across a grid-load resistor, as shown in Fig. 13-19. Let us assume that 0.1 microampere of signal current flows through the 15-megohm grid resistor. If we calculate the voltage drop, we find:



(a) input

(b) rectified output

Fig. 13-18

$$\begin{aligned}
 E_{\text{sig}} &= I_{\text{sig}} \times R_{\text{grid}} \\
 &= 0.1 \times 10^{-6} \times 15 \times 10^6 \\
 &= 0.1 \times 15 \\
 &= 1.5 \text{ volts}
 \end{aligned}$$

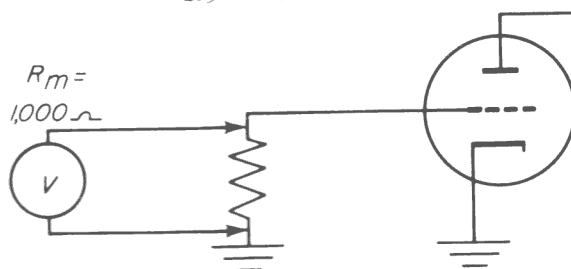


Fig. 13-19

However, when we place an iron vane meter with a resistance of 1,000 ohms across this circuit, the resistance from grid to ground looks like 1,000 ohms and not 15 megohms. Assuming that the signal current remains the same, we find that the signal voltage between grid and ground becomes:

$$\begin{aligned}
 E_{\text{sig}} &= 0.1 \times 10^{-6} \times 1 \times 10^3 \\
 &= 0.1 \times 10^{-3} \\
 &= 0.0001 \text{ volts}
 \end{aligned}$$

Such a small voltage would not cause the iron-vane meter to deflect, so we might assume that there was no signal voltage.

Among thermocouple meters, we find sensitivities up to 500 ohms per volt. While this is an improvement over the iron-vane meter, the loading effect of a thermocouple meter is still quite high. Thermocouple meters are satisfactory for use as a-c ammeters, but are nowhere near as sensitive as D'Arsonval movements equipped with a crystal-diode rectifier.

The sensitivity of the a-c section of your multimeter is 6,667 ohms per volt, which is more than 13 times as sensitive as the best thermocouple meter. What is more, your a-c scale is much more linear (particularly at the low-voltage end of the scale) than is a thermocouple meter. Like a thermocouple meter, it may be used to measure voltages in the audio and r-f ranges.